MONTANA FACT FINDING COMMITTEE ON HIGHWAYS, STREETS AND BRIDGES

INCREMENTAL METHOD

OF DETERMINING

MOTOR VEHICLE TAX RESPONSIBILITY

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An Analysis Developed

For The

Montana Fact Finding Committee

On

Highways, Streets and Bridges

By

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The Reason.

One of the main problems faced by any legislature is the equitable allotment of taxes amongst the recipients of benefits provided by the government. In the matter of distributing the costs of highway construction and maintenance, this problem is most difficult to solve because of the complex use of the facilities. Motor-vehicle users not only employ the highways for different purposes, but also impose different conditions upon its structure, requiring the improvement of standards in some cases, and contributing to the decline of existing facilities in others. Because of the complexity of the problem, the road tax structures in most States, while based on reasonable presumption and experience, fall far short of the desired goal of equity.

In recent years, highway tax studies throughout the States have sought to establish a firm basis, or measuring stick, for a reasonable and fair apportionment of highway costs amongst the users of highways. Different methods of analysis have been applied. The most common is probably the gross ton mile method, which would assign relative responsibility between motor vehicle groups according to the product of gross weight transported by vehicle miles travelled. This has the appearance of an equitable solution, since it takes into consideration the two major factors known to influence road costs; weight and relative use. However, the gross-ton mile theory fails to account for the actual relationship between weight and road costs and, in fact, is predicated on the assumption that such a weight cost relationship cannot be accurately determined. It, therefore, disregards known factors, and ignores the road in the assignment of tax responsibility. Another method of analysis which has been applied is the cost function method. This approach to the problem groups the different elements of construction and maintenance cost, according to the benefits provided to different classes of highway-user. Thus, there are "standby" costs which are apportioned to all vehicles equally; "non-weight-use" costs which are apportioned by relative use or vehicles miles; and "weight-use" costs which are apportioned to heavy vehicles by ton-miles. This is certainly a scientific approach to the problem. However, each detail of road construction does not easily fit a category where its benefits to one or another class of vehicle are clearcut. Considerable argument must result from application of the method. Other methods of analysis are likewise complicated, and often ignore the effect of the vehicle on the roadway.

Of all the methods applied, one stands out as both scientific and reasonable. This involves the engineering or incremental approach, and is sometimes called the method of differential costs. The following general description of the incremental method is taken from a memorandum to members of the Committee on Highway Taxation and Finance, Sub-committee No. 1B, of the Highway Research Board, dated December 1952.

"The salient characteristic of the incremental method, sometimes known as the method of differential costs, is that it purports to assign motor vehicle tax responsibility in proportion to the highway costs occasioned by

vehicles of different types and sizes. The use of the term "incremental" arises from the fact that most highway costs that are variable with size of vehicles may be considered as built up from a basic cost in which all vehicles share, and to which successive increments are added to accommodate the requirements of vehicles in ascending order of size."

For example: A flexible pavement structure composed of two inches of plant-mix asphalt, four inches of crushed rock cushion, and twelve inches of select, compacted sub-base material, would easily support considerable traffic of loaded two-axle vehicles weighing five tons. State practice may determine that three inches of plant-mix asphalt with the same supporting structure is necessary to accommodate the same traffic of eight ton two-axle vehicles. In making an incremental assignment, the first truck would only pay its share of the cost of the two-inch mat, since the additional thickness required for the larger vehicle is of no benefit to it. The second vehicle would pay its share of the two-inch mat, plus an additional share of the three-inch mat. Vehicles still larger would be assigned shares of the first two "increments" plus share of any additional thickness required for their accommodation.

Mr. D. F. Pancoast, in a report titled, "Allocation of Highway Costs in Ohio by the Incremental Method," makes the following pertinent remark: "It is important to note that the incremental method is used only for allocating the motor-vehicle share of highway costs. What that share should be, as compared to the share to be borne by abutting property, the general government, or other beneficiaries of highways, must first be determined by other means."

<u>The Method</u>

The incremental solution to the problem of allocating responsibility to motor-vehicle users for the cost of highway facilities is still in the development stage throughout the United States. Although certain concepts have been fairly well established, there is a wide range of possibilities in applying these concepts. Certain problems peculiar to each State warrant individual analysis. The purpose of this report is to describe the basis of a scheme of distribution of incremental costs which will relate to practical highway building in Montana. In order to compare this proposition with the most recent developments in application of the incremental method, a general description of studies performed by other States and agencies follows:

The most advanced thinking to date on the problems involved in making an incremental analysis is presented in a series of memoranda to members of the Committee on Highway Taxation and Finance of the Highway Research Board. Since the Fall of 1951, this Committee has been engaged in developing a framework for the incremental solution. Mr. D. F. Pancost, a contributing member to this study, has used much the same framework in developing an allocation of Highway Costs for the State of Ohio.

The essential method rests on the premise that the structure of a "basic" roadway can be determined for a given volume range of traffic, that will accommodate repetitions of axle loading by a defined "basic" vehicle. Four

or five volume classes of highways have usually been chosen. The highest class, Type A, is the only one assumed to accommodate vehicles imposing repetitions of the maximum legal axle load. (The use of axle loads as a criterion determining the need for thicker and more costly pavement develops from recent road tests which have proven this fundamental axle-load, thickness, relationship for both flexible and rigid pavement.) Within this volume class, increments of cost are distributed to intervals of axle loads between the maximum legal and the "basic" - in Mr. Pancoast's study, 4 kips - as the thickness of pavement structure, width of surface, width of shoulder, cost of shoulder treatment, etc. is assumed to decrease as necessary to accommodate load intervals of smaller magnitude. The engineer using the approach is faced with this problem in consideration of facilities not actually constructed: What thickness of pavement and type of related structure would be required in this volume class if traffic were composed of passenger cars only; or, to designate the next highest standard, if traffic were composed of vehicles imposing no more than 6K axle load; and so on.

The contributing members to the Highway Research Board have demonstrated that their individual judgment, or the judgment of the agency they represent, differs considerably in answering the problem. Considering passenger cars only, some engineers are, undoubtedly, influenced by the standards to which high-volume parkways are constructed. Others are influenced by the standard of construction which must be applied to combat the effect of the elements. No criticism of the framework which poses these problems is intended. A rigorous analysis, not subject to argument and debate at some point, has not yet been devised. However, a uniform assessment of responsibility to different weight groups of vehicles will not necessarily follow general adoption of the framework under consideration by the Highway Research Board. For every difference in judgment as to what constitutes a "basic" facility for a volume group, a different scale of relative responsibility will result.

The next highest volume class of facility, designated as Type B, under the framework of the above analysis, is not considered to accommodate sufficient repetitions of the maximum legal axle load so that it has an effect on the required highway structure. Although maximum legal axle loads are considered, they are charged with the same relative responsibility as the next lowest axle-load interval. Distribution of cost is made in the same way as for the Type A facility.

Type C facilities are handled in the same manner. In this case, axle loads greater than those for which the facility is primarily designed are charged with the same weight-effect as loads for which the facility is designed. This progressive reduction of weight charge, as volume accommodation provided by the structure becomes less, produces a triangular pattern of analysis. A rectangular pattern, where the full weight-effect of the vehicle is considered on all facilities, is also possible. However, this does not take into account the number of repetitions of axle load which is of considerable significance in design. A structure built to accommodate innumerable repetitions of a ten kip axle load will also accommodate some limited number of repetitions of an eighteen kip axle load. The amount of use that a heavy vehicle makes of a low-volume

facility will probably not produce sufficient repetitions of its axle load to fail the structure before it deteriorates from other cause. Therefore, the full weight-effect of the vehicle will not influence the structural design of this facility. At the same time, since design is largely a matter of engineering judgment, allowance is undoubtedly made for the greater weight-effect of the heavy vehicle. Since it is impossible to determine, with any degree of exactness, the extent to which this weight-effect influences structural requirements, the triangular distribution is more fair than the rectangular, but is definitely lenient towards heavy trucks. The triangular pattern will be discerned in the Montana analysis.

The distribution which has been described is for pavement cost alone. One of the essential considerations in this approach is the width of surface required by a given vehicle type. The defined "basic" vehicle is thought to require less width of travelling way. The assignment of grading and drainage cost in the Ohio analysis is based on the ratio of graded structure required to accommodate the "basic" vehicle to that required to accommodate trucks wider than the "basic" vehicle. A progressive assignment of these costs by weight is not made. A certain percent of cost is attributed to the "basic" vehicle; the remainder is shared alike by all other vehicles.

The Ohio analysis does not treat Type D facilities incrementally. These are non-surfaced roadways and weight is considered to have no effect in their structural requirements.

The framework of the Highway Research Board and Ohio solution may be simply illustrated as follows:

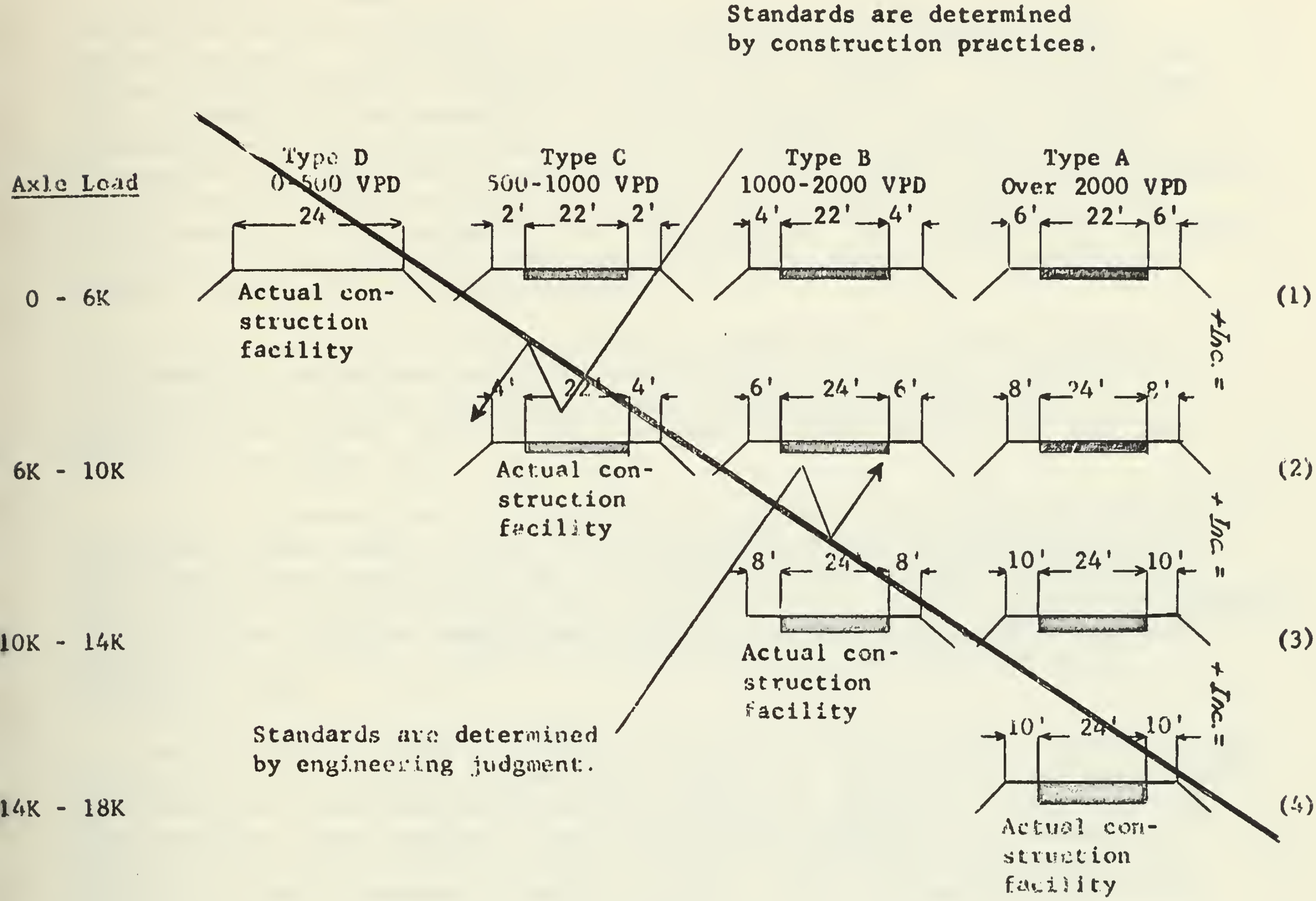

Figure 1.

Taking Type A as an example: The basic pavement (1) is charged to axle loads between 0 K and 18 K; the increment of cost between (1) and (2) is charged to axle loads between 6 K and 18 K; the increment between (2) and (3), 10 K and 18 K between (3) and (4), 14 K and 18 K. Eighty (80) percent of grading and drainage costs are charged to 0 - 6 K; 20 percent charged equally to all vehicles larger than those imposing 6 K. Maintenance is partially distributed by weight as determined by a multiple corelation and regression analysis;partially to all vehicles alike. Structures are treated incrementally by matching to above facilities, and distributing incremental costs in the same manner. Type D highways are not treated incrementally.

When dealing with Type B highways, the upper axle load interval, instead of reading "10K to 14K", should read "over 10K". By means of the illustration and example given, it is intended only to show the fundamental framework of analysis used in Ohio and considered by the Highway Research Board Committees.

Although the above approach to the incremental solution is entirely scientific, it is not proposed to abide entirely by its framework in the Montana analysis. One of the reasons a departure is contemplated is the amount of engineering judgment required to determine basic factors. In addition, the wide surface width designated for low-volume roadways in this State precludes consideration of width increment, since this geometric standard is chosen to accommodate the high speed of passenger cars. It is thought that the controversial definition of a "basic" vehicle, or "basic" facility can be avoided, and the solution which will be proposed avoids these definitions. In the Montana proposal, it is not so necessary to separate and individually describe the benefits of certain elements of construction cost.

So that the point of view of commercial users of the highways will not be overlooked in the Montana solution, consideration and study has been given to a recent report made by the Virginia Highway Users' Association, which incorporated both a cost function and incremental analysis designed to test tax equity in that State. (1)

It is noteworthy that the fundamental approach to the incremental analysis contained in that report is that of consideration of the actual facilities constructed in that State, rather than "mythical" facilities deemed necessary to meet needs when conditions other than reality exist. A similar "practical" approach in the Montana solution should prevent contention that an individual engineer's judgment has resulted in unfair tax allocation to the disadvantage of the commercial user.

An extensive breakdown of current construction and maintenance costs provides the basis for the Virginia Highway Users' solution. Elements of construction and maintenance cost are assigned separately, either as weight functions or general use functions. Axle loading is used as the weight criterion. Increments for width, pavement thickness, gradient, structures, and related maintenance, are assigned to weight-responsible vehicle groups. It is interesting to note that the potential of a vehicle to impose a given axle load is used in the pavement thickness assignment.

No special effort is made to relate a class of roadway to a vehicle-group accommodation, except that the State Class I highways are described as the predominate truck routes, and Class 2 highways as "mixed traffic" high-volume routes with a smaller proportion of truck traffic. Much the same standard of facility is provided for these two classes except for surface which is two feet wider on Class I, and gradient requirements which are more demanding on Class I.

These differences are attributed to the larger proportion of trucks on Class I, and comparison of these two facilities produces, first, an increment of width

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(1) Testing the equity of Virginia's Motor Vehicle Tax Structure - a Report to the Commission Established by Senate Joint Resolution Number 48. Submitted by the Virginia Highway Users' Association, June 1953.

for both surfaces and total graded structure, and, second, an increment of gradient for construction of the total graded structure. These increments are exclusively assigned to trucks, and essentially distributed by proportionate vehicle miles. Differences in surface width between Class II and Class III, and between Class III and Class IV routes of the Primary System are not considered attributable to weight or size. These are progressively lower volume routes.

All remaining pavement construction cost and related maintenance cost, for the Primary System, is distributed by weight-apportioned increments. About 60 percent of the maintenance of pavement on the Secondary System is distributed in the same way. However, construction cost of pavement on the Secondary System is not at all attributed to weight or size, presumably because this system is composed chiefly of local rural county roads.

Structures on all systems, primary and secondary, are essentially treated by weight criteria. The cost of all "basic" facilities, primary and secondary, and administrative expense is distributed by relative use, or vehicle miles.

At first glance the solution appears to be entirely equitable, in fact to work adversely for the heavy vehicle. Actually, it is "weighted" in favor of the heavy vehicle. The authors make much of the distribution of one or another cost factor entirely to trucks, when the accommodation provided would suggest a more equitable distribution. Actually, the proportion of costs unfairly distributed to the heavy vehicle, to the overall construction and maintenance cost. is small. On the other hand, a "weighting" of the solution in favor of trucks is inherent in the handling of pavement thickness.

Different types of pavement construction on the several facilities are not recognized, and pavement cost is made proportional to thickness entirely. This results in a very high relative standard for "basic" vehicle or passenger car accommodation. Analysis of non-partisan solutions in other States indicated the assignment to passenger cars may be as much as ten percent too high. The lack of consideration of weight effect on the underlying structure tends to destroy the argument of equitability. Also, although considerable passenger car mileage must have been travelled on the 40,000 miles of Secondary System by definition, this mileage is not subtracted when apportioning the cost of the "basic" facility in the relatively high-cost Primary System.

Class I and II highways only are compared for width increment, when, in fact, design standards cited call for less surface width on Class III and Class IV. Partly because of the high relative "basic" pavement on the Primary System, heavy vehicles are not considered responsible for any element of construction on the Secondary System, although one-third of that system is hard-surfaced.

A cost function analysis is presented along with the incremental analysis. The fundamental concepts applied to each are, to a degree, contradictory. In the cost-function analysis, engineering and administrative costs are defined

as "standby" costs, and argument is presented that these costs should not be distributed by relative use or vehicle mile criteria. They are apportioned by registration. In the incremental analysis, all of these costs are apportioned by relative use. Since the proportions by travel are different than the proportions by registration, (trucks generally travel more miles per vehicle), the cost function approach favors heavy vehicles in this respect.

There is no reason to divorce concepts applied to the incremental method from those applied to the cost-function method. An incremental analysis, to consider all aspects fairly, must incorporate the cost function approach. Some costs are fairly separated from relative-use or weight criteria, and should be charged on the basis of vehicle registration. The cost of collecting registration fees is an example. Payments to related departments and agencies, legal fees, grounds and buildings, some aspects of planning surveys, etc. bear little relationship to the relative use of facilities. Beautification and landscaping should probably be charged to passenger cars only.

However, engineering and administrative costs directly related to construction or maintenance are not different in character from pavement or grading item costs. If it entails more engineering and administrative expense to construct or maintain thick pavement than it does to construct and maintain thin pavement, a certain proportion of these costs may actually be weight functions. The administrative and engineering expense of constructing and maintaining the "basic" facility is reasonably distributed by relative use.

In the Montana analysis an approximate distribution of administrative expense by function will be undertaken. This will be accomplished by a process of elimination. First, administrative expense in no way related to the relative use of highways will be separated. Since there are not many costs in this category, this will not be too difficult a task. Second, "direct" engineering cost of construction and maintenance will be separated. (These costs are generally a fairly constant proportion of contract or force account construction and maintenance costs). These costs will be added to other costs of the facility considered, which will automatically cause them to be distributed incrementally. Remaining administrative costs will be apportioned along with the cost of the "basic" facility by relative use, or vehicle miles.

Before proceeding with the description of the Montana method, earlier investigations should be mentioned, which are notable for their contribution to present-day thinking on the incremental problem. They are as follows:

1. Report of the Interim Committee appointed by His Excellency, Charles H. Martin, Governor of the State of Oregon, for a study of the Motor Transportation Act and the fees and taxes paid by the

Road Users for the Highway Facilities provided by the State of Oregon - January 1, 1937.

2. Public Aids to Transportation, Volume IV, Public Aids to Motor Vehicle Transportation - Federal Coordinator of Transportation, 1940. (Often referred to as The Eastman Report).

Although other analyses have been made by the incremental method, both in the United States and in Canada, contributing to detail and structure, these have not been studied in detail since the fundamentals applicable to present studies have been "sifted" from the respective reports by Mr. Pancoast, Mr. St. Clair and others.

The Montana Solution

The Montana solution is being prepared under the auspices of the Montana Fact Finding Committee on Highways, Streets, and Bridges, in cooperation with the State Highway Department. The method of analysis is essentially designed to reflect present construction practice and engineering viewpoint in the State. As has already been stated, certain problems of highway construction and finance are peculiar to each State. An incremental analysis designed to fit the needs of the heavily populated eastern states would not, in all probability, result in a reasonable allotment of highway cost if applied in Montana.

Montana's peculiar problems arise from its topography which embraces extremes of very flat to very mountainous terrain; from its lack of densely populated centers which results in few high-volume traffic arteries; from its many attractions for tourists which results in a relatively large number of out-of-state vehicles on its highways; from the predominance of two major industries, farming and mining, which results in greater load applications on low-volume highways; from its situation with respect to other States and the mountain barrier. Highway costs, especially high in mountainous terrain, must be distributed among relatively few domestic highway users.

What, then, is desired, is a reasonable allotment of highway costs that will bear a scientific relationship to the use of highways by different vehicles imposing different conditions on the highway structure. It has been amply demonstrated that no method of analysis can rigidly fix responsibility for all elements of highway cost.

The basic premise of the Montana method of incremental allotment of highway costs is that each standard of facility constructed on a homogeneous highway (1) system is a "stage" in the construction of the next highest standard of facility. This premise is supported from a historical point of view by consideration of the manner in which highway systems have developed. Essentially, it has been a process of improving existing facilities to accommodate a more demanding traffic picture.

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(1) Each homogeneous highway system will be treated separately under the headings: Federal Interstate, Primary, and Secondary, without regard for administrative jurisdiction. Local rural roads and city streets are excluded from the determinations which follow. These systems will be studied separately. See the end of this text for further discussion.

As population centers have grown and as the efficiency of motor vehicles has been improved, it has been necessary to build connecting roadways to ever increasing geometric standards to accommodate more vehicles at higher speeds. As the use of highways for the transportation of freight has increased, it has been necessary to devise stronger structures to accommodate the heavy vehicle. New facilities may or may not have been built on top of existing roadbeds, but, regardless, they constitute improvement of existing facilities. The process still continues.

It is desirable to relate this process to the present program of highway construction which is expected to provide adequate highway facilities in this State within the next 20 years. Relative responsibility between motor vehicle users will be developed for a total highway product that will fit their needs. Although construction costs applied will be those estimated for the 20-year program, the relative responsibility so developed can be applied to a shorter range objective. The validity of the solution should last until a totally different pattern of highway needs becomes apparent.

Instead of defining a "basic" vehicle, or a "basic" facility as such, a base mean standard will be chosen, as actually constructed in the State, which will be related, by engineering judgment, to the accommodation of a specific upper limit of axle loading.

Consider the applicability of the basic premise to structural requirements. Except on special purpose roads such as parkways, it is usual to employ the highest structural standards on highways where there is sufficient composite traffic to produce considerable repetitions of the maximum legal axle load; and to relate, in design theory, the thickness of pavement to the magnitude of this load.

It is usual to employ lower structural standards for less traffic, because, where fewer repetitions occur, this same load is not considered to have the same significance. It does, perhaps, have the significance of loads of lesser magnitude which are produced in sufficient numbers to govern the reduced structural requirements.

Lower standards are employed for still smaller volumes of traffic. These standards may be similarly dictated by related axle loads which are produced in numbers by including not only loads of the related magnitude alone, but also all loads of larger magnitude operating, because of fewer repetitions, with less weight effect.

This is the usual concept applied to the incremental solution, and it is not unrelated to fact. It is obvious that a paved road designed to withstand innumerable repetitions of a 6,000 pound axle load will withstand some limited number of repetitions of the maximum legal load of 18,000 pounds (which will not influence its design as a load of that magnitude).

It is also a concept that can be applied to the increments of an integrated road structure. It is not difficult to visualize each increment as being related to a portion of the maximum load using the structure, and, in addition,, as being related to loads of such a magnitude as to require the thickness of increment, were it a separate road structure. Thus each increment would be a charge against that load and against that portion of the maximum load.

The basic premise of the Montana solution combines the two applications of the concept by stating, in effect, that a given standard of roadway, whose structure is determined by a related load, may exist by itself, or as part of a roadway built to higher standards.

It is possible to derive an empirical relationship between traffic volume and the magnitude of the repeated axle load. In answer to a questionnaire circulated by Mr. G. P. St. Clair, Chairman of the Committee on the Incremental Solution of the Highway Research Board, engineers from several eastern States contributed to this determination. An approximation of the results of their combined judgment is provided by the formula $L = .3\sqrt{V}$ where L is the maximum repeated load in thousands of pounds, and V is the traffic volume in vehicles per day.

Applying this formula to the several volume classes of roadway designated by the Automotive Safety Foundation for the construction of rural highways in Montana (1), the following relationships are established.

Maximum Traffic Volume (VPd)	$.3\sqrt{V}$	Maximum Axle * Load (Kips)
400	6	6
1000	9.5	10
2000	13.4	14
4000 **	19.0	18

* The last column is rounded for practical purposes.

** Considered a reasonable upper limit of two lane volume accommodation.

At traffic volumes which are less than 200 to 400 vehicles per day, there is a distinctive change in the type of surfacing recommended by the Automotive Safety Foundation. For this volume of traffic, and for larger volumes, weight dependent bituminous or portland cement concrete surfaces of intermediate or high type will usually be employed; for smaller volumes, low cost bituminous surfaces are contemplated. Although axle load is still an important factor in incurred cost on this surface type, it does not operate with the same uniformity of effect. It is for this reason that load-volume

(1) See Table III.

relationships are not listed for accommodations less than 200-400 vehicles per day.

A reasonable conclusion develops from the foregoing considerations: that each volume of composite traffic will produce repetitions of a determinate axle load in sufficient numbers to dictate structural requirements. The analysis which follows will demonstrate that the geometric standards required by each traffic condition are also reasonably related to the same order of axle loads, if axle load is assumed to be a fair measure of a vehicle's size and weight.

For this purpose, consider two two-lane highways, each built to geometric standards that will allow an average operating speed of 50-55 mph* to be maintained at all times, but each accommodating a different type of traffic. One carries vehicles of the general type of passenger cars, pickups, panel and stake trucks, whose gross weights will not exceed 5 tons, and whose widths are not more than 7 feet. The operating characteristics of these vehicles are assumed to be the same as those of passenger cars. The other carries the usual composite traffic found on Montana's rural highways, with 12 percent commercial vehicles whose maximum widths are 8 feet. The standard of gradient, a maximum of 3 percent, is indicated by the high operating speed. For the determination of relative geometric standards that are influenced by average conditions, a thirty percent restricted passing sight distance is assumed typical of the general terrain encountered in this State.

Using data from the Highway Capacity Manual, it is found that the practical capacity of the light vehicle facility is 522 vehicles per hour, i.e., 600 vehicles per hour reduced by the sight distance factor. On the other hand, the practical capacity of the heavy vehicle facility is only 324 vehicles per hour, since each commercial vehicle is equivalent to 6 passenger cars on a 3 percent grade with 30 percent restricted sight distance, ($284 + .14 \times 284 \times 6 = 522$). It is obvious that each facility does not provide equivalent accommodation for its respective traffic. However, if sight distance is further restricted on the roadway with light vehicles, so that the resulting factor is $324 \div 600$, parity is reached. Thus 75 percent restricted sight distance on the facility accommodating light vehicles with a 3 percent grade is equivalent to 30 percent restricted sight distance on the facility accommodating heavy trucks with a 3 percent grade.

Now consider limiting geometric standards that must be introduced for economic reasons on sections of the two roadways. Where desirable grades cannot be constructed, operating speeds will be compromised. Engineers will increase gradient to a limiting condition where the maximum possible capacity of a facility is realized. As grades are steepened, operating speed is reduced, and capacity is increased, until the optimum capacity of any two-lane highway is achieved at 30 mph. Both lanes are full and all traffic is proceeding at that speed. Grades on the roadway carrying the 5-ton vehicles may be increased to 6 percent for optimum capacity since these trucks are capable of sustaining 30 mph on such a grade (1). However, although capacity can be

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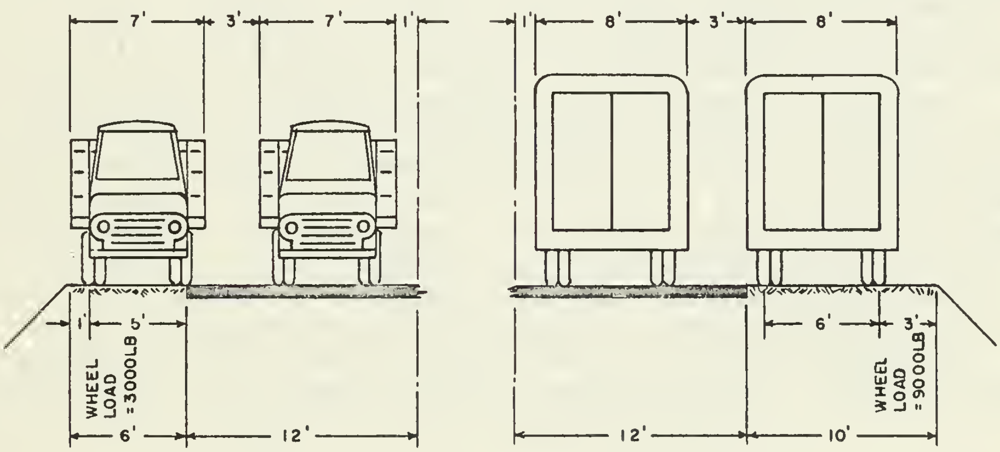
* Considered desirable in Montana.
(1) Highway Capacity Manual, Fig. 20.

increased on the facility carrying the heaviest trucks, optimum capacity can never be realized since these vehicles cannot sustain 30 mph even on 3 percent grades. (1) Because reduction in grade for parity in this consideration would cause a disproportionate practical capacity, and because the cost of obtaining better sight distance and that of obtaining better gradient, which are the two variables, are in the same order of magnitude, it is sufficient to assume equivalence between the 6 percent and 3 percent grades on the two facilities with their respective traffic.

Let us extend the comparison to other geometrics. Adequate shoulders render a service capacity-wise and safety-wise by providing a place to park disabled vehicles out of the traffic stream. It is apparent that the two facilities being examined must provide similar accommodation for the largest vehicles they carry, if the same relative effect on capacity and safety is to result. Because lighter vehicles are able to park closer to the lip of a fill slope, 6-foot shoulders will provide almost the same accommodation for 7-foot wide stake trucks that 10-foot shoulders will provide for 8-foot wide combinations. The following diagram will illustrate.



Thus, when capacity is used as a criterion, the following geometric differences occur between the accommodation provided for vehicles of 5 tons gross vehicle weight, and those provided for the heaviest trucks.

	Vehicles of 5-Tons GVW	Heaviest Vehicles
Passing Sight Distance	25%	70%
Gradient	6%	3%
Shoulders	6'	10'

(1) Climbing Lane Theory and Road Test Results by T. S. Huff and F. H. Scrivner, of the Texas Highway Department. Vehicle Climbing Lanes, Highway Research Board Bulletin 104, 1955, p. 10, Fig. 18.

"Any traffic variable or any roadway condition that prevents vehicles from moving safely at a speed of 30 miles per hour lowers a roadway's capacity." - Highway Capacity Manual.

In addition to the geometric standards already considered, there are those that are not so easily analyzed for proportionate weight assignments. Stopping sight distance, for example, is influenced by many factors. Relative speed is a large consideration in this respect. In flat terrain, on good alignment, the law imposes a speed differential between passenger cars and trucks by limiting the latter to 45 mph, whereas cars may be expected to travel at speeds near to 70 mph.

In mountainous terrain, the opposite extreme, gradient and relatively poor alignment impose their own restrictions. Trucks are forced to proceed slowly and passenger car speeds are considerably reduced on ascending grades. Both types of vehicle tend to travel at the same speed on descending grades. For reasonable economy, design speed tends to approach this average operating speed. Shorter stopping sight distances are employed. It is in this terrain that the highest order of cost is incurred by sight distance requirements, and it is with this terrain that we shall begin an analysis.

Since minimum sight distance requirements will apply to the downgrades, and since all vehicles travel downgrade at approximately the same speed, standards are largely influenced by the braking performance of different types of vehicles. At a typical speed of 40 mph, passenger cars and "very light vehicles," as defined in a recent publication by the Bureau of Public Roads, will be able to stop in 198 feet (1), (driver stopping distance), plus a downgrade factor. The heaviest 5 and 6 axle combinations will be able to stop in 335 feet, plus a downgrade factor. If this factor is 50 feet on a typical 6 percent grade, designers would be able to employ a 248-foot stopping sight distance for light vehicles, and a 385-foot stopping sight distance for heavy vehicles. Without consideration of the height of line of sight, this produces an assignment of 35.6 percent of the cost of providing stopping sight distance to trucks over 5 tons gross vehicle weight. However, the height of a driver's eyes purchases sight distance on vertical curves (but not to a large extent on horizontal curves). Therefore, the above percentage of weight assignment should be reduced. Although vertical control is likely to be imposed more often, each horizontal control is likely to incur more relative cost in steep sidehill cuts and fills. For this reason a 30 percent weight assignment is considered reasonable.

There is little justification for charging heavy vehicles with any of the costs incurred to provide adequate stopping sight distance in level terrain. Passenger cars at 70 mph require the same braking distance that heavy trucks require at 50 mph. Since sight distance is much less costly in this case, a 20 percent overall average weight assignment is reasonable. This might be considered applicable to the in-between topographic condition described as rolling terrain.

There is little use trying to derive the exact order of costs that are assignable to heavy vehicles considering curvature as a separate geometric standard. Justification for a difference of a degree or so in their presence is found in superelevation practices. Where maximum super rates cannot be used on

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(1) Braking Performance of Motor Vehicles. - Published by the Bureau of Public Roads, Washington, D. C. 1954, p. 108.

grades where heavy vehicles might slide to the inside shoulder, curvature is restricted and additional cost incurred. The tracking width of heavy vehicles requires the widening of some curves of 7 degrees and over. For these reasons, and because curvature is closely allied to the provision of sight distances, the order of weight-assignable costs is assumed to follow that of other geometric standards.

Now let the order of geometric differences that have been attributed to vehicles heavier than 5 tons be examined:

	Vehicles of 5 Tons GVW	Heaviest Vehicles
Passing Sight Distance	25%	70%
Gradient	6%	3%
Shoulders	6'	10'
Non-Passing Sight Distance *	.80(525) = 420'	525'

* Approximate assignment in rolling terrain.

From Table III, Design Standards of Rural State Highways, it is apparent that the order of geometric difference listed above is the same order of geometric difference that has been recommended between two-lane facilities carrying 200-400 vehicles per day and those carrying 2000-4000 vehicles per day. The latter is related structurally to 18,000-pound axle loads; geometrically to vehicles which will impose an 18,000-pound axle load. The former is related structurally to 6,000-pound axle loads; geometrically to vehicles which will impose a maximum 6,000-pound axle load. Therefore, geometric differences may be equitably assigned along with structural differences as each relates to a traffic condition and as each, in turn, relates to the same range of axle loads.

Thus, there is logically established a "base mean standard" for this analysis, which is that facility designated by the Automotive Safety Foundation to provide adequate accommodation for 200-400 vehicles per day. Its structure and geometrics are related to innumerable repetitions of a 6-K axle load which are created not only by loads of that magnitude alone, but by all loads of greated magnitude using the structure. It may exist as a structure by itself, or as part of a structure accommodating more weight and more traffic volume.

Before proceeding further, it is well to review and consider those elements of roadway structure whose cost will be wholly or partially assigned by weight in this incremental analysis. This is best accomplished by considering what differences occur between the base mean standard and highest type two-lane highway. There will be differences in: pavement structure; type of pavement; thickness and type of base; and width and treatment of shoulders. It will be noted that there is no difference in roadway surface width.

The Automotive Safety Foundation and engineers of the State Highway Department have been influenced, in choosing geometric standards for this State, by certain characteristics of motor vehicle operation peculiar to Montana. Although there are night-time speed limits, and zones of limited

speed, there are no further restrictions on the speed of passenger cars in this State. Trucks are limited to 45 mph. As a result, average operating speeds are 5-10 mph higher than the national average. To provide safety and comfort at high expected speeds, a twenty-four foot width of travelling surface is the absolute minimum to be constructed on any highway. The people of Montana desire this accommodation. Engineers feel entirely justified in giving it to them as a result of the savings in maintenance and replacement cost that will be realized. The edges of plant-mix pavement, not subjected to heavy loads, will not ravel as they have done in the past, and Montana's highway engineers have found certain decided advantages to the exclusive use of plant-mix rather than road-mix or penetration-type pavement. Although the weight factor provides justification, State highway men are insistent that the 24-foot width of travelling surface on low-volume facilities is an accommodation which is essentially provided for passenger vehicles.

The differences in pavement structure; type of pavement; and thickness and type of base are obviously weight-determinable elements. It has been demonstrated that a four to six ratio of shoulder width is a legitimate weight assignment. However, the structural soundness of highway shoulders needs further consideration. In this respect, the results of the WASHO road test are significant. By effecting containment of materials in the whole underlying road structure, structurally sound, well-consolidated shoulders add considerable stability to the paved travelling surface itself. Some engineers in the Highway Research Board have recommended extending full thickness of pavement to the shoulder for this purpose. It is obvious that heavy vehicles parking on the shoulder will require a stronger shoulder structure. It is for these reasons that the treatment of shoulders contemplated on large volume facilities is legitimately considered a size and weight requirement.

At this point it may be mentioned that it is only those geometrics that have a proven relationship to weight that will be charged along with related structural costs. The costs of obtaining and marking right-of-way; other costs of controlling access; the beautification and provision of recreational facilities, etc. will be subtracted from the weight apportionment.

Other geometrics and differences in structural cost are related by volume accommodation to their respective axle loads as follows:

Axle Load Interval (Kips)	Volume Accommodated (VPD)
- 6	200 - 400
6 - 10	400 - 1000
10 - 14	1000 - 2000
14 - 18	2000 - 4000

According to the basic premise, the 200-400 roadway is included in all higher volume roadways as a "stage" in their construction. Therefore, the total mileage of the 200-400 VPD facility considered in the analysis is the mileage of all two-lane facilities accommodating 200 VPD upwards in any homogeneous highway system. (1) The total mileage of the 400-1000 facility is the mileage of all two-lane facilities in the system accommodating more than 400 VPD, and so on. The estimated cost per mile of constructing each standard will be determined from Automotive Safety Foundation and State Highway Department cost determinations. The differences in cost per mile between standards will be incrementally assigned to vehicles in accordance with the axle loads they impose. The total cost of the weight-assigned structure in a system will be later determined by multiplying vehicular responsibility per mile of any standard by the number of miles of that standard figured as above. The details of this distribution and reintegration will become apparent as the discussion continues.

Vehicles will be grouped under different types by Gross Vehicle Weight classification. The maximum potential axle loading of each Gross Vehicle Weight class will be determined. Each axle load will be first applied to its own interval and related roadway increment according to its potential. It will then be applied to each increment below its own requirement, assuming the proportions of the maximum axle load in the interval related to that increment. The load on each axle, as applied in each interval, (or related increment), will be multiplied by the vehicle miles that the related Gross Vehicle Weight class travels on the facility in the system which includes that increment. This establishes a relative measure of use of the interval. Mileage projected to mid-point of the program period will be used. Table I illustrates the distribution. The increment of cost per mile of construction that is required to accommodate each increasing axle load interval is developed as follows:

DEVELOPMENT OF INCREMENTAL COSTS

Volume Class (V.P.D.)	Construction Cost Per Mile ($)	Increment of Cost Per Mile ($)	Axle Load Accommodated (Kips)
200 - 400	30,000		
400 - 1000	45,000	15,000	6 - 10
1000 - 2000	56,000	11,000	10 - 14
2000 - 4000	66,000	10,000	14 - 18

This cost will then be apportioned by kip-axle-miles to axles using the increment. All of the figures are for illustrative purposes only.

(1) See footnote, page 9.

TABLE 1

FIGURES FOR ILLUSTRATIVE PURPOSES ONLY

TYPE OF VEHICLE BY G.V.W. CLASS	NO. AXLES IN GROUP & AV. MAXIMUM LOAD FRONT	INTER	REAR	ANNUAL VEHICLE MILES (X1000) 2000 VPD +	ANNUAL KIP AXLE MILES (X1000) @$.011111 14-18	ANNUAL VEHICLE MILES (X1000) 1000 VPD +	ANNUAL KIP AXLE MILES (X1000) @$.007333 10-14	ANNUAL VEHICLE MILES (X1000) 400 VPD +	ANNUAL KIP AXLE MILES (X1000) @$.003125 6-10	ANNUAL VEHICLE MILES (X1000) 200 VPD +	ANNUAL KIP AXLE MILES (X1000) @$ 2-6
FARM TRUCKS											
40,000 - 38,000	1@8		2@16	450	14400	900	25200	1100	30800	1600	28800
38,000 - 36,000	1@6		2@16	700	22400	1600	44800	2400	48000	3500	63000
36,000 - 34,000	1@6		2@15	600	18000	2500	120000	3500	70000	4000	72000
34,000 - 32,000	1@6		2@14			6000	168000	9000	180000	12000	216000
32,000 - 30,000	1@5		2@13			7000	182000	9000	180000	12000	204000
30,000 - 28,000	1@5		2@12			7000	168000	10000	200000	13000	65000
30,000 - 28,000	1@11		1@18	400	7200	2000	50000	2500	50000	4000	48000
28,000 - 26,000	1@10		1@18	700	12600	3000	42000	4000	80000	6000	72000
26,000 - 24,000	1@8		1@18	1500	27000	4000	56000	6000	108000	12000	144000
ETC.											
COMMERCIAL TRUCKS											
42,000 - 40,000	1@10		2@16	600	19200	1200	33600	2200	66000	5000	90000
ETC.											
SEMI-TRAILERS											
32,000 - 30,000			2@16	2200	70400	3500	98000	5000	100000	7000	84000
ETC.											
18,000 - 16,000			1@18	4000	72000	6000	84000	9000	90000	12000	72000
ETC.											
FULL TRAILERS											
48,000 - 46,000	1@14		2@16	800	25600	900	37800	1100	33000	1200	21600
ETC.											
8,000 - 6,000		2@4								50	400
ETC.											
TOTAL CUMULATED THOUSAND-POUND AXLE MILES					900000		1500000		4800000		50500000

The use of kip-axle-miles as described on the following page is now modified. Investigation of the traffic actually transported by facilities in this State has disclosed that the number of total axle miles of travel determines the magnitude of repeated axle load as it relates to traffic volume accommodated. The relationship is a smooth logarithmic curve and $A = a \log L + b$, where A is the number of axle miles and L is the repeated load. Thus the efficiency of a load is defined, dependent on the number of axle miles that loads of that magnitude travel on a roadway. The axle miles travel by each load will be multiplied by a factor equal to

$$\frac{N}{a \log L + b}$$

where N is the number of axle miles travelled by all loads of the same magnitude. This has the effect of assuring that load and axle miles have the same effect on cost. We are indebted to Mr. D. F. Pancoast of Ohio for suggesting that some such determination should be made.

APPORTIONMENT OF INCREMENTAL COSTS

Volume Group Accommodating Axle Load Interval	Annual Kip-Axle Miles (x 1000)*	Increment of Cost Required ($)	Increment Cost per Thousand Kip-Axle-Miles (Cents)
200 - 400	50,500,000	Developed by Different Process	
400 - 1000	4,800,000	15,000	.31250
1000 - 2000	1,500,000	11,000	.73333
2000 - 4000	900,000	10,000	1.11111

* From Table I.

The use of kip-axle-miles, or thousand-pound axle miles, is a new concept in this analysis. It has the effect of distributing the responsibility within each interval by weight, so that vehicles near the borderline of decreased responsibility are not penalized in favor of vehicles near the borderline of increased responsibility. The use of potential axle loads, to be determined from a vehicle's registered weight, is considered a better criterion of its responsibility in the requirement of higher-standard roadways than the use of axle loads actually imposed which might be derived from loadometer data. The public cannot be expected to underwrite uneconomic operation.

It will be noted that to this point only the weight responsibility of vehicles imposing more than 6 K axle load may be determined. The argument supporting the use of kip-axle-miles stated that this criterion avoided penalty near the borderline of weight responsibility. To extend this argument further, the weight-charge against each larger axle load should increase on a fairly uniform curve. This is both desirable and reasonable for tax allocation. And it is practical to develop a uniform curve of increasing weight responsibility by the following procedure. Having determined the relative responsibility per kip-axle-mile for axle load intervals with divisions at the upper limits of 10 K, 14 K, and 18 K, it is possible to plot the responsibility so determined on axes representing these loads. The curve so developed, may be mathematically extended to cut the 6 K axis and establish a weight-cost at that point. This cost will be the charge per kip-axle mile for some undefined increment of construction accommodating axle loads between 2 K and 6 K. It will be applied to this interval in Table I. Although the foregoing responsibility is not rigidly defined, it is a reasonable development, avoiding penalty to vehicles on the borderline of responsibility, and in keeping with the trend of increasing weight responsibility.

It is not necessary or practical, to define weight responsibility for vehicles with 2 K or less axle load. Gross Vehicle Weight classification does not apply below 6000 pounds. Vehicles with axle loads of 2 K or less travel 75 percent of all mileage on our highways. By neglecting weight-responsibility

in this bracket, the effect, by the method of elimination developed in this analysis, will be to transfer any weight-cost chargeable to this group to the cost of the undefined basic highway required by all axle loads, which will be distributed in the ratio of their annual travel by vehicle-miles. (Non-weight-use costs.) Vehicles with axle loads to and including 2 K will bear the largest share of the cost of the basic highway: ergo, they will bear the largest share of weight-cost so transferred.

Multi-lane facilities, assumed to be necessary to properly accommodate any volume in excess of 4,000 VPD, will be handled as follows. Each additional two lanes will be considered, structurally, as equivalent mileage of the highest-type two-lane facility. This mileage will be multiplied by the unit responsibility of each Gross Vehicle Weight class for this standard, as developed from Table I. The sum of these charges is then the "weight-charged" portion of the total cost of the multi-lane highway. The remaining portion, the cost of medians, right-of-way, control of access, etc. will automatically fall in the cost of the residual, or basic, highway which will be charged to all groups by vehicle miles.

Where an additional climbing lane is provided, because operating speeds are reduced by the presence of slow trucks, its cost will be determined and distributed separately. State Highway engineers have pointed out that these additional lanes, although required where heavy vehicles are present, are not exclusively provided for their accommodation. If passenger cars and lighter trucks were willing to slow down, their provision would not be necessary. The accommodation is largely to maintain the operating speeds desired by operators of the lighter vehicles. The ideal solution to the problem of distributing the cost of these climbing lanes would be a solution in which the effect of the slow-moving vehicle on decelerating traffic would create a "weighted" assignment of cost against them. Fortunately, such a solution is easily derived from a practical and provable standpoint, and as easily applied.

Highway capacity studies have derived the equivalence of trucks in terms of passenger cars on various grades. As an example: if, on a 7 percent grade, of a given length, it is found that one truck, of a given type and weight, has the same effect on decelerating traffic as 10 passenger cars; and if it is found that the same truck on level grade is equivalent to 2 passenger cars, it has five times the effect in decelerating traffic than it is already paying for in the incremental distribution. This truck and passenger car will then be charged with the additional cost of the climbing lane at a ratio of 5 to 1.

Having determined to this point the unit responsibility of each Gross Vehicle Weight class for each weight-apportioned increment of roadway in a system, it is now possible to sum all of these costs to obtain the part of the total cost assigned by weight. For example: Commercial trucks in the 34,000 to 36,000 Gross Vehicle Weight class have axles which travel 140,000 thousand kip-axle-miles on the standard accommodating 14 to 18 kips at 1.11111 cents per mile of this standard constructed; 260,000 thousand kip-axle-miles on 10 - 14 K at 0.73333 cents per mile of construction; 400,000 on 6 - 10 K at 0.31250 cents; 600,000 on 2 - 6 K

at 0.07321 cents. There are 400 miles of 14 - 18 K, which includes equivalent mileage of four-lane facilities; 1500 miles of 10 - 14 K, which includes the 400 miles that this standard is a "stage" of the 14-18 K accommodation; 2500 miles of 6 - 10 K which includes the 1500 miles of higher standard; and 4,000 miles of 2 - 6 K, which includes the 2,500 miles of all higher-type facilities. Then, the weight charge assigned to this vehicle group is (1400 x 1.11111) 400 / (2600 x 0.73333) 1500 / (4000 x 0.31250) 2500 / (6000 x 0.01321) 4000 Or $8,364,250. The sum of weight charges assigned to each vehicle group is the total weight-cost of the constructed system. All figures used in the above example are illustrative only.

To the weight-cost, determined as above, will be added the cost of additional climbing lanes which will be separately assigned; of beautification, landscaping, waysides, picnic sites, historical markers, and other recreational facilities with appropriate signs, which will be separately assigned to passenger cars. The result will be subtracted from the total cost of all construction on the system to leave a residual which must be on the cost of the basic element of construction which is required and used by all vehicle groups alike. The cost of the basic highway will then be distributed to the vehicle groups in proportion to their use of the highway system, or, in other words, be vehicle miles.

This residual, which is the cost of the basic system structure since the analysis is performed separately by systems, will include the cost of sections of unsurfaced highway in the Secondary System. The resulting assignment of some cost to heavy vehicles for roads which they may not actually use is supported by the following considerations. First, it must be remembered that the Secondary System does not include local rural roads which represent 75 percent of all rural mileage. The Secondary System is designed to "feed" the Primary and Interstate Systems. Although heavy vehicles do not make use of unsurfaced feeder routes at this time, they may do so in the future, and are reasonably considered responsible for this "stage" in the construction process. From a point of view of economics, all State roads generate the product which is carried by heavy commercial vehicles on primary highways. To the extent that this is true, most, if not all, classes of highway user derive benefits from all roads, and should be charged with some proportion of their cost. Therefore, allocation of the cost of the basic structure in the main feeder system by relative use of the system as a whole is fair and just, even though the basic structure includes some roads which heavy commercial vehicles do not use.

Maintenance Cost.

The method of elimination developed in the handling of construction costs may be extended, practically, to the allotment of maintenance costs, so that it will not be necessary to consider each element of cost and the resulting benefits to one or another vehicle group. Each facility considered as a "stage" in the incremental solution has its prototype on the present highway system. Essentially, the process

will involve comparison of prototypes of the different standards for average annual maintenance cost. Each set of standards so compared will be similarly situated, so far as possible, with respect to topography, weather, and type of soil. The average annual cost of maintaining each prototype over a period of years will be computed. All costs which do not at all relate to the use of facilities will be subtracted in the derivation of this figure. These will include costs of landscaping, beautification of campsites, historical markers sidewalks and foot paths, etc. Costs not arising from the normal usage of highways such as the costs of major slide removal and washout repair, channel changes, riprap, etc., will be subtracted. The remaining average annual cost of maintaining each standard of facility will be multiplied by a factor so that the total cost of maintaining all standards will equal a sum estimated to meet maintenance expenditures on the system for the program period. This latter figure will be exclusive of costs of landscaping, beautification of campsites, historical markers, etc. which will be developed for the same period and separately charged to passenger cars. The total maintenance cost of each standard for the program period will then be added to the construction costs developed for each standard, before increments of cost are calculated for distribution to the several weight groups. Increments of maintenance cost chargeable by weight may or may not develop. The "residual" will automatically become the cost of maintaining the basic facility, and will be distributed by relative use.

Cost of Highway Structures

The cost of constructing major highway appurtenances, such as bridges over 20 feet in length and underpasses, will be allotted by the same method as the cost of constructing the roadway itself is allotted, although a separate incremental distribution will be necessary. For simplicity, underpasses will be considered as bridges on the upper highway. The average cost per foot of length of constructing a bridge that will "match" each standard of roadway will be determined. For example: H-20 loading is considered for the design of bridges accommodating over 2000 vehicles per day; H-15 loading for volumes between 200 and 2000 VPD; H-10 loading for less than 200 VPD. Here the weight relationship between different volume accommodation is apparent in the way it influences designers to select these different standards. Differences in width will result because of differences in shoulder width. Since the shoulder requirement is attributable to weight and the effect of heavy vehicles on traffic, so must the differing bridge widths be considered.

After costs are determined for each standard of facility, differences or increments of cost per foot of length will be computed. These increments will be distributed to each Gross Vehicle Weight class of vehicles of different types, using the same kip-axle-mile figures employed in the roadway analysis, substituting unit costs per foot of structure for unit costs per mile of roadway.
A unit cost figure for the 2 - 6 K axle load interval will be developed in the same way. The unit vehicular responsibility in each axle load interval will be multiplied by the length of related structure in the system. A total weight-

distributed cost will be developed, and when this is subtracted from the total cost of structures in the system, the residual will be the cost of the "basic" structure, which will be distributed by relative use.

Tunnels are the only major structures which remain to be considered. The increments of cost in their construction will not be in the same ratio as average increments developed for bridges and underpasses. Because of the small number of these facilities that may be built, a separate incremental distribution of their cost will not be worthwhile. As an end result of the analysis, a chart will be set up showing the total of all charges against each Gross Vehicle Weight class of vehicle under the different type headings. By multiplying each cost by the same index, the cost of tunnels and miscellaneous costs not otherwise considered will be covered. In other words, the relative scale will not be influenced by their inclusion or exclusion, but a figure will be secured for the program period.

Administrative Costs

The proposed method of handling administrative costs has already been described. A minimum of selection is anticipated, and the usual method of elimination will be used. Those costs which can be directly related to the construction of various standards of facilities, e.g., a fixed proportion of construction cost for engineering, will be added to other construction costs before the incremental distribution is made. Thus, some of these costs will be apportioned by weight. Costs definitely not related to highway use, such as the costs of motor vehicle registration, legal costs, payments to related departments and agencies, etc. etc. etc., will be separated and charged in proportion to the number of vehicles registered. The remaining administrative costs, considered as contributing to construction and maintenance, will be distributed by relative use or vehicle miles.

The Secondary System

The argument and analysis which has been presented is based primarily on standards devised for the State Primary System. However, it can be shown that the same relative difference in accommodation is provided between corresponding volume classes on the Secondary System. Economy dictates that the geometrics of secondary highways be somewhat lower than the geometrics of primary highways, classification for classification. Structural standards are also slightly lower, because heavy vehicles do not make as much use of secondary facilities. The 200-400 VPD accommodation is still the "basic mean standard" and relates to repetitions of a 6k axle load. The 400-1000 VPD accommodation is the highest volume class of roadway to be constructed on this system, and relates to innumerable repetitions of a 10 K axle load. Axle loads larger than 10 K will be charged with the same responsibility, since vehicles imposing these loads do not use the system to the extent they use the Primary, and facilities are not specifically designed for their accommodation. Again, this produces the triangular distribution, lenient towards the heavy vehicle. Weight responsibility will be extended downwards to 2 K by the mathematics developed for the Primary System. Residual cost will be developed and distributed in the same way.

Structures, maintenance, and administration will be handled similarly. Table IV shows the design standards that the Automotive Safety Foundation have developed for the State Secondary System.

Federal Interstate System

Table II shows the design standards designated by the Automotive Safety Foundation for the Rural Interstate System. It will be noted that volume classifications are not used. However, the essential equivalence between standards selected for this system and those designated for roadways carrying more than 2000 VPD in the Primary System will be realized from comparison of Table II and Table III. Therefore, increments of weight cost developed for the Primary System will be employed in the distribution of cost of Interstate highways. The System will be handled separately, and separate mileage figures of vehicular use will be derived. Residual costs, structures, maintenance, and administration will be apportioned in the same manner as on the Primary System.

Local Rural Roads and City Streets

In a State where the motor-vehicle share of the cost of providing adequate highway facilities must be spread over relatively few domestic users, it is of paramount importance that the cost burden of local rural roads be distributed in a fair and equitable manner. The Montana Fact Finding Committee on Highways, Streets and Bridges is cooperatively engaged with the Montana Agricultural Experiment Station in a study to determine the relative benefits derived from highway development by users and other beneficiaries of highways. Together with this incremental analysis, the user portion of the cost of local rural roads will be allocated.

Although commercial vehicles use this system very little, these roads, nevertheless, generate the product that the commercial vehicle carries on Primary highways. However, the farmer, who is the main user, does realize a particular benefit from these facilities. There is a tie, in this repsect, with the concept that the local rural road provides a large service to adjacent property. If the agencies studying the problem do find and recommend that the services rendered property is a substantial consideration in the apportionment of local rural road costs, and that property should be taxed accordingly, then the farmer may be considered to have been charged with his especial responsibility. The remaining cost of local rural roads would be reasonably apportioned equally to all vehicles registered in the State.

City streets will be studied separately. Some consideration will be given to zoning ordinances, and the type of enterprise a given street is intended to serve. This will affect the method used to distribute the motor vehicle user's share of the cost of these facilities. For example: In industrial zones where the street is built to service heavy vehicles, an incremental, (weight distribution), of cost would be in order. In commercial zones, an incremental distribution might be made to include the weight of axles of the heaviest vehicles

that commonly use the related streets. It does not appear that the incremental method should be applied to residential streets. A study is under way by the State Planning Survey, under the auspices of your Committee to develop the proportionate use of different classes of city streets. Where the incremental analysis is used, it is intended to apply the concepts and method developed in this report with appropriate modification.

General

The advantages of the proposed method of incremental analysis, compared with other methods, may be enumerated as follows:

(1) The number of considerations and assumptions is reduced to a minimum. The load-structure relationships on which the analysis is based are easily visualized, being related to actual construction.

(2) No controversial definition of a basic vehicle or basic facility is necessary.

(3) Once the premises are accepted as reasonable and just, it is impossible to prejudice the solution against any class of highway user.

(4) The solution is valid until the whole pattern of highway needs is changed.

(5) The proportionate responsibility developed is validly fitted to a program of "stage construction."

(6) Structures may be "matched" to the facility they serve, and the same method of incremental distribution applied to them.

(7) Maintenance costs may be related to facilities which will actually be constructed, and to prototypes which are now being maintained on the present highway system. A minimum of definition of benefits is involved, and no prejudice possible.

(8) Some administrative cost may be distributed incrementally.

A pictorial outline of the methology of the Montana solution is presented in Figure II. Although the problem is complex, and copious argument must be produced to describe and support the allotment of each element of cost to the motor vehicle user, it can be seen that the distribution itself is relatively simple. Once the premises of the solution are accepted as reasonable, little is left to an individual engineer's judgment. The analysis is completely without prejudice to any class of user on the highways. Careful consideration of the details discloses that where one of the premises apparently works to the disadvantage of a particular vehicle type, an offsetting advantage is produced

by another consideration. Equitability is achieved where exactness can not be determined. It is on this basis that support of the solution is solicited from all interested groups. Constructive criticism will be appreciated. No figures have, as yet, been applied to the method so that it is impossible to say what relative costs will result. All data necessary for the solution, however, has been secured by your Fact Finding Committee.

One additional problem remains to be considered as it relates to the incremental solution. This concerns the allotment of Federal-aid funds to the highway construction program. The form of analysis herein described takes no account of this source of revenue, in developing the scale of relative responsibility by which vehicles should be taxed. This is entirely as it should be. The relative responsibility of any vehicle group is not affected by the source of income which builds the highways. When the cost responsibility of the vehicle groups for a system is developed, and if moneys to build the system come from sources other than the motor-vehicle user, the whole curve of relative costs for that system should be adjusted accordingly. This may be accomplished by subtracting the "outside" income from the cost of the "basic" roadway structure in the system, which is apportioned to all vehicle groups on the same basis. Thus, the weight-responsibility curve is not destroyed. If the Federal Tax Structure obviously recovers moneys from given weight groups out of proportion to the defined responsibility, an adjustment can be made by subtracting the moneys so recovered from the amount this State would collect from the same weight groups, and "crediting" the lesser amount of Federal-aid to the cost of the "basic" structure.

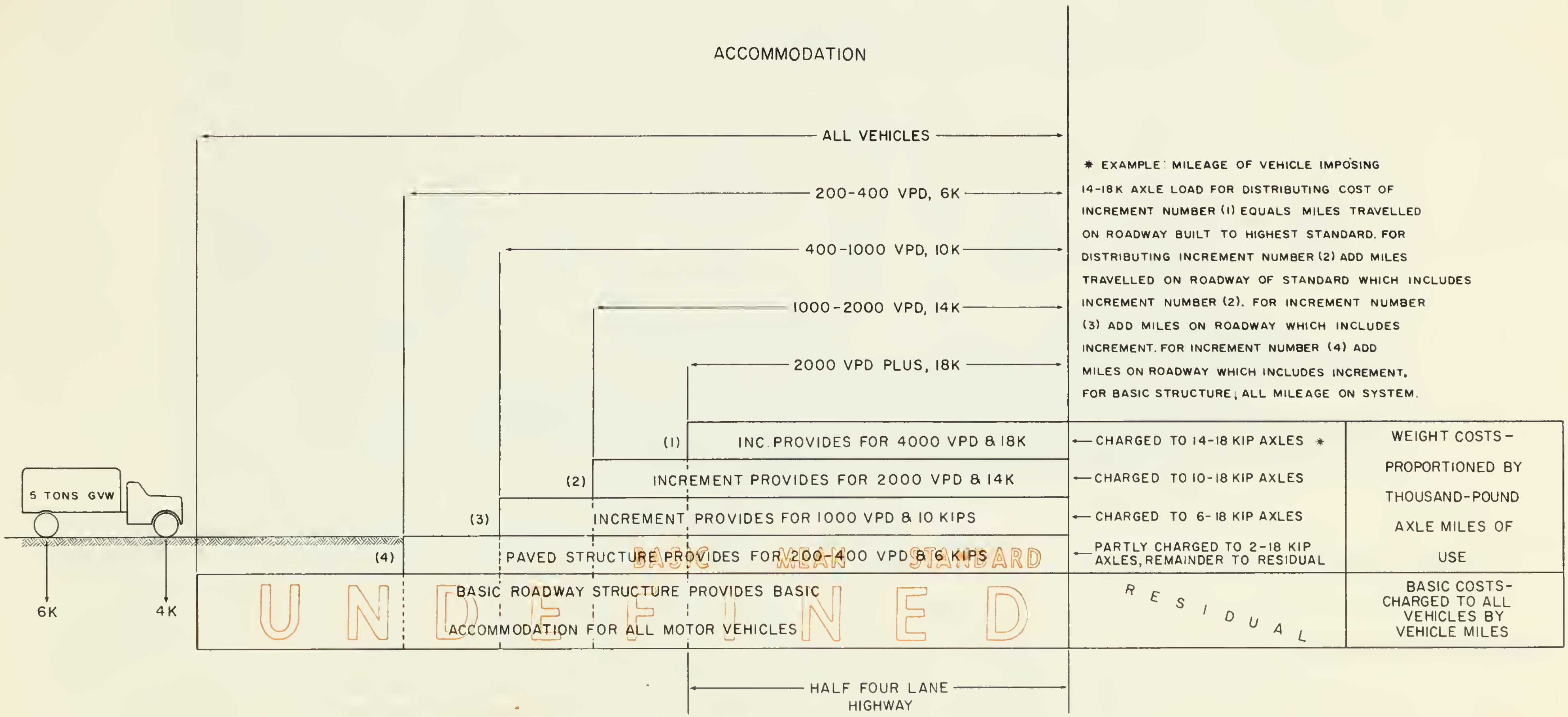
This report is still in a preliminary stage. It is addressed to members of the Montana Fact Finding Committee on Highways, Streets, and Bridges; to members of the Incremental Advisory Committee; to the people of this State; and to all interested groups. Written comments should be addressed to Mr. Wm. L. Hall, Executive Director of the Montana Fact Finding Committee. The following are members of the Incremental Advisory Committee: Mr. Scott P. Hart, State Highway Engineer; Mr. Mort Flint, District Engineer, Bureau of Public Roads; and Dr. E. R. Dodge, Dean of Civil Engineering, Montana State College. The analysis has been prepared by Ralph D. Johnson, Research Engineer, Montana Highway Department, under advisement of the Incremental Advisory Committee.

FIGURE II

MONTANA FACT FINDING COMMITTEE
ON
HIGHWAYS, STREETS, AND BRIDGES

INCREMENTAL SOLUTION

DISTRIBUTION OF HIGHWAY COSTS TO MOTOR VEHICLE USERS
ON
PRIMARY AND INTERSTATE HIGHWAY SYSTEMS



MONTANA FACT FINDING COMMITTEE
ON
HIGHWAYS, STREETS, AND BRIDGES
AUTOMOTIVE SAFETY FOUNDATION, CONSULTANTS

Table II

DESIGN STANDARDS FOR RURAL INTERSTATE SYSTEM ROUTES

		Multi-Lane			2-Lane		
Terrain Class		Flat	Rolling	Mountain	Flat	Rolling	Mountain
Design Speed — MPH		70	60	50	70	60	50
Operating Speed — MPH		50-55	45-50	40-45	50-55	45-50	40-45
Surface Type		Type I-High					
Lane Width — Feet		12					
Shoulder Width — Feet		10	8-10	(1) 4	10	8-10	(1) 4
Shoulder Type		Full Width-Bituminous Seal and Cover					
Maximum Curvature — Degree		3	5	7	3	5	7
Maximum Gradient — Percent		3	4	(2) 5	3	4	(2) 5
Stopping Sight Distance — Feet		700	525	400	700	525	400
(3) Min. % Passing Sight Distance Available Per Mile	1500'	Not Applicable			10	10	–
	800'				–	–	10
(4) Maximum 1976 DHV (Equivalent Passenger Vehicles) — Percent of Applicable Sight Distance Available	100%	1000 Per Lane	1200 Per Lane	1300 Per Lane	600	900	800
	80%				550	800	680
	60%				495	690	520
	40%				420	580	275
Minimum Median Width — Feet		(5) 20		4	Not Applicable		
Minimum Right of Way Width — Ft.		200' Without Frontage Roads 300' With Frontage Roads			150' Without Frontage Roads 250' With Frontage Roads		
Control of Access		Required			(6) Required 1956 DHV Exceeds 300. Partial Control of Access Permissible Where 1956 DHV is Less Than 300.		
(7) Bridges	Loading	H 20 – S 16					
	Clearance Width – Feet	Bridges 100 Ft or Less in Length – Full Approach Roadway Width (Including Usable Shoulders). Bridges Over 100 Ft in Length – Approach Pavement Width Plus 3 Foot Offset From Barrier Curbs.					
	Vertical Clearance – Feet	16					
(8) Railroad Separations		All Railroad Crossings			All Main Line Crossings With 2 or More Tracks All Single Track Main Line Crossings with 1956 DHV Over 200.		
Highway Separations		All Cross Roads and Places of Access			(9)		

(1) Wherever Feasible 8' Shoulders Should Be Provided in Mountainous Areas.
(2) Gradients in Rugged Terrain of 6 Percent, And in Unusual Conditions of 7 Percent, May Be Provided.
(3) Passing Sight Distance in Mountainous and Heavy Rolling Topography Shall Be The Highest Obtainable With Reasonable Economy. Capacity Analysis Will Determine Need For Truck Climbing Lanes.
(4) Equivalent Passenger Car Capacities To Be Adjusted For Percent of Commercial Vehicles and Grades
(5) Median Width of 40 Feet Desirable.
(6) For Partial Control of Access, Intersections at Grade (Public Roads and Private Drives) Shall Not Exceed Two Per Side Per Mile, 1956 ADT Shall Not Exceed 50, and Access Rights Between Such Intersections Are Acquired.
(7) Standards Apply to Interstate Highway Bridges, Overpasses, and Underpasses. Standards For Crossroad Overpasses and Underpasses Shall Be Those for the Crossroad.
(8) Appropriate Protective Devices Shall Be Provided at all Railroad Grade Crossings.
(9) All Cross Roads and Places of Access Where Full Control of Access is Required. All Intersections With 1956 ADT of 50 or More on Sections Where Partial Control of Access is To Be Provided.

MONTANA FACT FINDING COMMITTEE
ON
HIGHWAYS, STREETS, AND BRIDGES
AUTOMOTIVE SAFETY FOUNDATION, CONSULTANTS

Table III

DESIGN STANDARDS FOR RURAL STATE HIGHWAYS
(OTHER THAN INTERSTATE SYSTEM ROUTES)

	Multi-Lane			2-Lane														
1976 ADT	(1)			(1) Over 2000			1000 to 2000			400 to 1000			200 to 400			Under 200		
Terrain Class	Flat	Rolling	Mtn.	Flat	Rolling	Mtn	Flat	Rolling	Mtn	Flat	Rolling	Mtn	Flat	Rolling	Mtn	Flat	Rolling	Mtn
Design Speed — MPH	70	60	50	70	60	50	70	60	50	70	60	50	60	50	40	60	50	40
Operating Speed — MPH	50-55	45-50	40-45	50-55	45-50	40-45	45-50	45-50	40-45	45-50	45-50	40-45	45-50	40-45	35-40	45-50	40-45	35-40
Surface Type	Type 1-High									Type 2-Intermediate						Type 3-Low		
Lane Width — Feet	12																	
Shoulder Width — Feet	10	8-10	(2) 4	10	8-10	(2) 4	8	8	4	8	8	4	6	6	4	4	4	4
Shoulder Type	Bituminous Seal and Cover												Gravel					
Maximum Curvature — Degree	3	5	7	3	5	7	3	5	7	4	6	9	6	9	12	6	9	12
(3) Maximum Gradient — Percent	3	4	6	3	4	6	3	4	6	4	5	7	5	6	7	5	7	7
(3) Stopping Sight Distance — Ft	700	525	400	700	525	400	600	475	350	600	475	350	475	350	275	475	350	275
(3) Min % Passing Sight Distance Available Per Mile — 1500'	Not Applicable			10	10	-	10	10	-	Wherever Feasible								
800'				-	-	10	-	-	10									
(4) Maximum 1976 DHV (Equivalent Passenger Vehicles) — Percent of Applicable Sight Distance Available — 100	1000 Per Lane	1200 Per Lane	1300 Per Lane	600	900	800	Not Applicable											
80				550	800	680												
60				495	690	520												
40				420	580	275												
Min. Right of Way Width — Feet	(5) 200' Without Frontage Rds. 300' With Frontage Rds.			150									100					
Bridges — Loading	H-20 — S-16															H-15 — S-12		
Bridges — Clearance Width — Feet	(6)			30									28					
Bridges — Vertical Clearance — Feet	16									14								
(7) Railroad Separations	All Main Line Crossings			On Main Line Crossings With 6 or More Trains Per Day or Exposure Factor of 10,000 or More									Not Required					

(1) Multi-Lane Highway Required Where a Two-Lane Highway Will Not Provide Capacity for 1976 ADT.
(2) Wherever Feasible 8' Shoulders Should Be Provided in Mountainous Areas on Highways Carrying Traffic in Excess of 2000 ADT
(3) Gradient and Sight Distance Standards for Volumes of Over 2000 ADT in Mountainous or Heavy Rolling Topography Shall Be the Highest Obtainable with Reasonable Economy. Capacity Analysis Will Determine Need For Truck Climbing Lane on Two-Lane Roads
(4) Equivalent Passenger Car Capacities To Be Adjusted for Percent of Trucks and Grades
(5) Partial Control of Access Required for All Multi-Lane Construction on New Location. Minimum Median Width of 20 Feet in Flat and Rolling Terrain and 4 Feet in Mountainous Terrain. Wider Median Widths Should Be Provided Wherever Feasible
(6) Under 80 Feet in Length Full Approach Roadway Width. Over 80 Feet in Length Approach Pavement Width Plus 3 Foot Offset from Barrier Curbs
(7) Appropriate Protective Devices Shall Be Provided at All Railroad Grade Crossings Where Exposure Factor (Trains Per Day X ADT) 3000

Table IV

MONTANA FACT FINDING COMMITTEE
ON
HIGHWAYS, STREETS, AND BRIDGES
AUTOMOTIVE SAFETY FOUNDATION, CONSULTANTS

DESIGN STANDARDS FOR SECONDARY HIGHWAYS

1976 ADT		400 to 1000 (1)			200 to 400			100 to 200			50 to 100			25 to 50			Under 25		
Terrain Class		Flat	Rolling	Mts	Flat	Rolling	Mts	Flat	Rolling	Mts	Flat	Rolling	Mts	Flat	Rolling	Mts	Flat	Rolling	Mts
Design Speed – MPH		60	50	45	50	45	40	45	40	35	40	30	25	40	30	25	40	30	25
Surface Type		Type 2 Intermediate Bituminous			Type 3 Low Bituminous			Type 3 Low Bituminous			Type 4 Gravel – Heavy Course			Type 4 Gravel – Medium Course			Type 4 Gravel – Light Course		
Surface Width – Feet		24	24	24	24	24	22	24	24	22	24	24	22	22	22	20	20	20	20
Roadway Width – Feet		32	32	28	30	30	26	28	28	26	24	24	22	22	22	20	20	20	20
Maximum Curvature – Degree		5	7	10	7	10	12	10	12	17	12	22	40	12	22	40	12	22	40
Maximum Gradient – Per Cent		5	6	7	5	6	7	5	6	7	5	7	9	5	7	9	5	7	10
Stopping Sight Distance – Feet		475	350	315	350	315	275	315	275	240	275	200	165	275	200	165	275	200	165
Maximum Right of Way Width-Ft.		120			100			100			66			66			66		
Bridges	Loading	H20-S16			H15-S12			H15			H15			H10			H10		
	Clear Width-Feet	28			26			26	26	24	24	24	22	22	22	20	20		
	Vertical Clearance-Ft	14			14			14			14			14			14		
Railroad Crossing Protection		Grade Separation When Exposure Factor Exceeds 10,000 – Flashing Lights When Exposure Factor Exceeds 3,000 Reflectorized Warning Signs At All Other Crossings – (Exposure Factor = 1976 ADT X Trains per Day)																	

(1) Use Design Standards for Rural State Highways When 1976 ADT Exceeds 1000
(2) In Built-up Suburban Areas Use Municipal Street Standards